

NOVEL POTASSIUM CHANNELS AND GENES ENCODING THESE POTASSIUM CHANNELS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a divisional of co-pending Application No. 09/590,304, filed on June 9, 2000 (for which priority is claimed under 35 U.S.C. §120), which is a conversion of provisional application U.S. 60/139,891 filed June 22, 1999 (for which priority is claimed under 35 U.S.C. §119). The entire contents of both of these applications are hereby incorporated by reference. This application also claims priority of Application No. PA1999-00828 filed in Denmark on June 11, 1999 under 35 U.S.C. § 119.

TECHNICAL FIELD

This invention relates to novel potassium channels and genes encoding these channels. More specifically the invention provides isolated polynucleotides encoding the KCNQ5 potassium channel subunit, cells transformed with these polynucleotides, transgenic animals comprising genetic mutations, and the use of the transformed cells and the transgenic animals for the *in vitro* and *in vivo* screening of chemical compounds affecting KCNQ5 subunit containing potassium channels.

BACKGROUND ART

Potassium channels participate in the regulation of electrical signalling in excitable cells, and regulates the ionic composition of biological fluids. Mutations in the four known genes of the *KCNQ* branch of the K^+ -channel gene family underlie inherited cardiac arrhythmia's, in some cases associated with deafness, neonatal epilepsy, and the progressive hearing loss of the elderly (presbycusis).

Ion channels play important roles in signal transduction and in the regulation of the ionic composition of intra- and extracellular fluids. KCNQ1 is a typical member of the voltage-gated potassium channel superfamily with 6 transmembrane domains and a pore region situated between the fifth and the sixth transmembrane domain. The minK protein (also known as KCNE1 or Isk) has a single transmembrane span and cannot form potassium channels on its own. However, as a β -subunit it enhances and modifies currents mediated by KCNQ1. These heteromeric channels participate in the repolarization of the heart action potential. Certain mutations in either *KCNQ1* or *KCNE1* cause a form of the autosomal dominant long QT syndrome (LQTS), a disease characterised by repolarization anomalies of cardiac action potentials resulting in arrhythmias and sudden death. Interestingly, other mutations in either gene lead to the recessive Jervell and Lange-Nielsen (JLN) syndrome that combines LQTS with congenital deafness. In order to cause deafness, KCNQ1/minK currents must be reduced below levels that are already sufficiently low to cause cardiac arrhythmia.

Mutated and non-mutated KCNQ2 and KCNQ3 potassium channels have been disclosed in WO 99/07832, WO 99/21875 and WO 99/31232.

SUMMARY OF THE INVENTION

We have now cloned and characterised KCNQ5, a novel member of the KCNQ family of potassium channel proteins. KCNQ5 forms heteromeric channels with
5 other KCNQ channel subunits, in particular KCNQ3 and KCNQ4.

The present invention has important implications for the characterisation and exploitation of this interesting branch of the potassium channel super family.

Accordingly, in its first aspect, the invention provides an isolated polynucleotide having a nucleic acid sequence which is capable of hybridising under at
10 least medium stringency conditions with the polynucleotide sequence presented as SEQ ID NO: 1, its complementary strand, or a sub-sequence thereof.

In another aspect the invention provides a recombinantly produced polypeptide encoded by the polynucleotide of the invention.

In a third aspect the invention provides a cell genetically manipulated by the
15 incorporation of a heterologous polynucleotide of the invention.

In a fourth aspect the invention provides a method of screening a chemical compound for inhibiting or activating or otherwise modulating the activity on a potassium channel comprising at least one KCNQ5 channel subunit, which method comprises the steps of subjecting a KCNQ5 channel subunit containing cell to the
20 action of the chemical compound; and monitoring the membrane potential, the current, the potassium flux, or the secondary calcium influx of the KCNQ5 channel subunit containing cell.

In a fifth aspect the invention relates to the use of a polynucleotide sequence of the invention for the screening of genetic materials from humans
25 suffering from neurological diseases for mutations in the *KCNQ5* gene.

In a sixth aspect the invention relates to the chemical compound identified by the method of the invention, in particular to the use of such compounds for diagnosis, treatment or alleviation of a disease related to diseases or adverse conditions of the CNS, including affective disorders, Alzheimer's disease, anxiety,
30 ataxia, CNS damage caused by trauma, stroke or neurodegenerative illness, cognitive deficits, compulsive behaviour, dementia, depression, Huntington's disease, mania, memory impairment, memory disorders, memory dysfunction, motion disorders, motor disorders, neurodegenerative diseases, Parkinson's disease and Parkinson-like motor disorders, phobias, Pick's disease, psychosis, schizophrenia, spinal cord damage,
35 stroke, tremor, seizures, convulsions and epilepsy.

In a seventh aspect the invention provides a transgenic animal comprising a knock-out mutation of the endogenous *KCNQ5* gene, a replacement by or an additional expression of a mutated *KCNQ5* gene, or genetically manipulated in order to over-express the *KCNQ5* gene or to over-express mutated *KCNQ5* gene.

In an eighth aspect the invention relates to the use of the transgenic animal of the invention for the *in vivo* screening of therapeutic compounds.

Other objects of the invention will be apparent to the person skilled in the art from the following detailed description and examples.

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DETAILED DISCLOSURE OF THE INVENTION

The present invention provides novel potassium channels and genes encoding these channels. The invention also provides cells transformed with these
10 genes, transgenic animals comprising genetic mutations, and the use of the transformed cells and the transgenic animals for the *in vitro* and *in vivo* screening of drugs affecting KCNQ5 containing potassium channels.

Polynucleotides

15 In its first aspect, the invention relates to novel nucleic acid molecules encoding a polypeptide comprising all or a portion of a KCNQ5 protein.

In a preferred embodiment, the polynucleotides of the invention are such which have a nucleic acid sequence capable of hybridising under at least medium stringency conditions with the polynucleotide sequence presented as SEQ ID NO: 1,
20 its complementary strand, or a sub-sequence thereof.

The polynucleotides of the invention include DNA, cDNA and RNA sequences, as well as anti-sense sequences, and include naturally occurring, synthetic, and intentionally manipulated polynucleotides. The polynucleotides of the invention also include sequences that are degenerate as a result of the genetic code.

25 As defined herein, the term "polynucleotide" refers to a polymeric form of nucleotides of at least 10 bases in length, preferably at least 15 bases in length. By "isolated polynucleotide" is meant a polynucleotide that is not immediately contiguous with both of the coding sequences with which it is immediately contiguous (one on the 5' end and one on the 3' end) in the naturally occurring genome of the organism from
30 which it is derived. The term therefore includes recombinant DNA which is incorporated into an expression vector, into an autonomously replicating plasmid or virus, or into the genomic DNA of a prokaryote or eukaryote, or which exists as a separate molecule, e.g. a cDNA, independent from other sequences.

The polynucleotides of the invention also include allelic variants and
35 "mutated polynucleotides" having a nucleotide sequence that differs from the sequence presented as SEQ ID NO: 1 at one or more nucleotide positions. The mutated polynucleotide may in particular be a polynucleotide of the invention having a nucleotide sequence as in SEQ ID NO: 1, which sequence, however, differs from SEQ ID NO: 1 so as to effect the expression of a variant polypeptide. The mutated polynucleotide may be

a polynucleotide of the invention having a nucleotide sequence encoding a potassium channel having an amino acid sequence that has been changed at one or more positions. The mutated polynucleotide may in particular be a polynucleotide of the invention having a nucleotide sequence encoding a potassium channel having an amino acid sequence that has been changed at one or more positions located in the conserved regions, as defined by Table 1, below.

Hybridisation Protocol

The polynucleotides of the invention are such which have a nucleic acid sequence capable of hybridising with the polynucleotide sequence presented as SEQ ID NO: 1, its complementary strand, or a sub-sequence thereof, under at least medium, medium/high, or high stringency conditions, as described in more detail below.

In a preferred embodiment the polynucleotide is a fragment of at least 15 bases in length which is sufficient to permit the fragment to hybridise to DNA that encodes a polypeptide of the invention, preferably the polypeptide having the amino acid sequence presented as SEQ ID NO: 2 under at least medium, medium/high, or high stringency conditions, as described in more detail below.

Suitable experimental conditions for determining hybridisation between a nucleotide probe and a homologous DNA or RNA sequence, involves pre-soaking of the filter containing the DNA fragments or RNA to hybridise in 5 x SSC [Sodium chloride/Sodium citrate; cf. *Sambrook et al.*; Molecular Cloning: A Laboratory Manual, Cold Spring Harbor Lab., Cold Spring Harbor, NY 1989] for 10 minutes, and pre-hybridisation of the filter in a solution of 5 x SSC, 5 x Denhardt's solution [cf. *Sambrook et al.*; *Op cit.*], 0.5 % SDS and 100 µg/ml of denatured sonicated salmon sperm DNA [cf. *Sambrook et al.*; *Op cit.*], followed by hybridisation in the same solution containing a concentration of 10 ng/ml of a random-primed [Feinberg A P & Vogelstein B; Anal. Biochem. 1983 **132** 6-13], ³²P-dCTP-labeled (specific activity > 1 x 10⁹ cpm/µg) probe for 12 hours at approximately 45°C.

The filter is then washed twice for 30 minutes in 2 x SSC, 0.5 % SDS at a temperature of at least at least 60°C (medium stringency conditions), preferably of at least 65°C (medium/high stringency conditions), more preferred of at least 70°C (high stringency conditions), and even more preferred of at least 75°C (very high stringency conditions).

Molecules to which the oligonucleotide probe hybridises under these conditions may be detected using a x-ray film.

DNA Sequence Homology

In a preferred embodiment, the polynucleotides of the invention show a homology of at least 65%, preferably at least 70%, more preferred at least 80%, even more preferred at least 90%, most preferred at least 95%, with the polynucleotide
5 sequence presented as SEQ ID NO: 1.

As defined herein, the DNA sequence homology may be determined as the degree of identity between two DNA sequences indicating a derivation of the first sequence from the second. The homology may suitably be determined by means of computer programs known in the art such as GAP provided in the GCG program
10 package [*Needleman S B and Wunsch C D, Journal of Molecular Biology* 1970 **48** 443-453] using default parameters suggested herein.

Cloned Polynucleotides

The isolated polynucleotide of the invention may in particular be a cloned
15 polynucleotide.

As defined herein, the term "cloned polynucleotide", refers to a polynucleotide or DNA sequence cloned in accordance with standard cloning procedures currently used in genetic engineering to relocate a segment of DNA, which may in particular be cDNA, i.e. enzymatically derived from RNA, from its natural
20 location to a different site where it will be reproduced.

Cloning may be accomplished by excision and isolation of the desired DNA segment, insertion of the piece of DNA into the vector molecule and incorporation of the recombinant vector into a cell where multiple copies or clones of the DNA segment will be replicated, by reverse transcription of mRNA (reverse transcriptase
25 technology), and by use of sequence-specific oligonucleotides and DNA polymerase in a polymerase chain reaction (PCR technology).

The cloned polynucleotide of the invention may alternatively be termed "DNA construct" or "isolated DNA sequence", and may in particular be a complementary DNA (cDNA).

30 It is well established that potassium channels may be formed as heteromeric channels, composed of different subunits. Also it has been established that the potassium channel of the invention may form heteromers with other KCNQ's, in particular KCNQ3 and KCNQ4, when co-expressed with these subunits. In addition, potassium channels can associate with non-homologous subunits (β -subunits), e.g.
35 the KCNE1 (also known as minK or Isk), the KCNE2 (also known as the minK-related peptide (MiRP1), the KCNE3 (also known as MiRP2), the KCNE4 (also known as MiRP3), and/or the KCNE5 (also known as KCNE1L) subunit, that co-assemble and functionally modulate these channels or lead to a specific localisation within the cell.

Therefore, in a preferred embodiment, the polynucleotide of the invention is cloned and either expressed by itself or co-expressed with polynucleotides encoding other subunits, in particular a polynucleotide encoding a KCNQ3 channel subunit or a polynucleotide encoding a KCNQ4 channel subunit.

5 In another aspect of the invention, isolated and purified KCNQ5 antisense oligonucleotides can be made and a method utilised for diminishing the level of expression of KCNQ5 by a cell comprising administering one or more KCNQ5 antisense oligonucleotides. By KCNQ5 antisense oligonucleotides reference is made to oligonucleotides that have a nucleotide sequence that interacts through base
10 pairing with a specific complementary nucleic acid sequence involved in the expression of KCNQ5 such that the expression of KCNQ5 is reduced. Preferably, the nucleic acid sequence involved in the expression of KCNQ5 is a genomic DNA molecule or mRNA molecule that encodes KCNQ5. This genomic DNA molecule can comprise regulatory regions of the *KCNQ5* gene, the pre- or pro- portions of the
15 *KCNQ5* gene, or the coding sequence for mature KCNQ5 protein.

The term "complementary to a nucleotide sequence" in the context of KCNQ5 antisense oligonucleotides and methods therefor means sufficiently complementary to such a sequence as to allow hybridization to that sequence in a cell, i.e. under physiological conditions. The KCNQ5 antisense oligonucleotides
20 preferably comprise a sequence comprising of from about 8 to about 100 nucleotides, more preferably of from about 15 to about 30 nucleotides.

The KCNQ5 antisense oligonucleotides can also include derivatives which comprise a variety of modifications that confer resistance to nucleolytic degradation such as e.g. modified internucleoside linkages modified nucleic acid bases and/or
25 sugars and the like. Examples of such derivatives include backbone modifications such as phosphotriester, phosphorothioate, methylphosphate, phosphoramidate, phosphorodithioate and formacetal as well as morpholino, peptide nucleic acid analogues and dithioate repeating units.

The usefulness of antisense molecules have been described by e.g.
30 *Toulme & Helene, Gene* 1988 **72** 51-58; *Inouye, Gene* 1988 **72** 25-34; *Uhlmann & Peyman, Chemical Reviews* 1990 **90** 543-584; *Robertson, Nature Biotechnology* 1997 **15** 209; and *Gibbons & Dzau, Science* 1996 **272** 689-693, which publications are hereby incorporated by reference.

35 Biological Sources

The isolated polynucleotide of the invention may be obtained from any suitable human or animal source. In a preferred embodiment, which the polynucleotide of the invention is cloned from, or produced on the basis of a cDNA library, e.g. of the retina, skeletal muscle, or brain, in particular the cerebral cortex, occipital pole, frontal

and temporal lobes, putamen and the hippocampus, and in the piriform cortex, the entorhinal cortex, the pontine medulla and the facial nucleus, and in the cerebellum. In a more preferred embodiment, which the polynucleotide of the invention is cloned from, or produced on the basis of a cDNA library of the thalamus. Commercial cDNA
5 libraries are available from e.g. Stratagene and Clontech.

The KCNQ5 gene of the invention has been localised to the long arm of chromosome 6 (6q14).

The isolated polynucleotide of the invention may be obtained methods known in the art, e.g. those described in the working examples below.

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Preferred Polynucleotides

In a preferred embodiment, polynucleotide of the invention has the polynucleotide sequence presented as SEQ ID NO: 1.

In another preferred embodiment the polynucleotide of the invention is a
15 sequence giving rise to KCNQ5 channels subunits comprising one or more substitutions.

In another preferred embodiment the polynucleotide of the invention is a sequence giving rise to KCNQ5 channels subunits comprising one or more substitutions in the conserved regions, as defined in more details below.

20 It has been demonstrated that KCNQ channels often show alternative splicing and therefore may occur as isoforms originating from the same gene. Such isoforms as well as the different cDNA sequences from which they occurred are also contemplated within the scope of the present invention.

Finally the genes encoding KCNQ channel subunits in other species have
25 been found to differ slightly from the human genes. However, genes of other species, e.g. mouse, rat, monkey, rabbit, etc., are also contemplated within the scope of the present invention.

Recombinantly Produced Polypeptides

30 In another aspect the invention relates to novel KCNQ5 proteins. More specifically, the invention relates to substantially pure functional polypeptides that have the electrophysiological and pharmacological properties of a KCNQ5 channel, or KCNQ5 channel subunits. The novel polypeptides of the invention may be obtained by the polynucleotides of the invention using standard recombinant DNA technology.

35 In a preferred embodiment, a polypeptide of the invention is the KCNQ5 potassium channel having the amino acid sequence presented as SEQ ID NO: 2, and biologically active fragments hereof.

Modifications of this primary amino acid sequence may result in proteins which have substantially equivalent activity as compared to the unmodified

counterpart polypeptide, and thus may be considered functional analogous of the parent proteins. Such modifications may be deliberate, e.g. as by site-directed mutagenesis, or they may occur spontaneous, and include splice variants, isoforms, homologues from other species, and polymorphisms. Such functional analogous are also contemplated according to the invention.

Moreover, modifications of this primary amino acid sequence may result in proteins which do not retain the biological activity of the parent protein, including dominant negative forms, etc. A dominant negative protein may interfere with the wild-type protein by binding to, or otherwise sequestering regulating agents, such as upstream or downstream components, that normally interact functionally with the polypeptide. Such dominant negative forms are also contemplated according to the invention.

In the context of this invention, the term "variant polypeptide" means a polypeptide (or protein) having an amino acid sequence that differs from the sequence presented as SEQ ID NO: 2 at one or more amino acid positions. Such variant polypeptides include the modified polypeptides described above, as well as conservative substitutions, splice variants, isoforms, homologues from other species, and polymorphisms.

As defined herein, the term "conservative substitutions" denotes the replacement of an amino acid residue by another, biologically similar residue. Examples of conservative substitutions include the substitution of one hydrophobic residue such as isoleucine, valine, leucine or methionine for another, or the substitution of one polar residue for another, such as the substitution of arginine for lysine, glutamic for aspartic acid, or glutamine for asparagine, and the like. The term conservative substitution also include the use of a substituted amino acid residue in place of an un-substituted parent amino acid residue provided that antibodies raised to the substituted polypeptide also immune-react with the un-substituted polypeptide.

KCNQ1 Numbering System

In the context of this invention, amino acid residues (as well as nucleic acid bases) are specified using the established one-letter symbol.

By aligning the amino acid sequences of a polypeptide of the present invention to those of the known polypeptides, a specific amino acid numbering system may be employed, by which system it is possible to unambiguously allot an amino acid position number to any amino acid residue in any KCNQ channel protein, which amino acid sequence is known.

Such an alignment is presented in Table 1, below. Using the ClustalX computer alignment program [Thompson JD, Gibson TJ, Plewniak F, Jeanmougin F, & Higgins DG: The ClustalX windows interface: flexible strategies for multiple sequence

alignment aided by quality analysis tools; Nucleic Acids Res. 1997 25 (24) 4876-82], and the default parameters suggested herein, the amino acid sequence of a polypeptide of the present invention (hKCNQ5) and the amino acid sequences of the known polypeptides hKCNQ2-4 are aligned with, and relative to, the amino acid sequences of the known polypeptide hKCNQ1 (also known as KvLQT1). In the context of this invention this numbering system is designated the KCNQ1 Numbering System.

In describing the various enzyme variants produced or contemplated according to the invention, the following nomenclatures have been adapted for ease of reference:

Original amino acid / Position / Substituted amino acid

According to this nomenclature the substitution of serine for glycine at position 329 of Table 1 is designated as "G329S".

Table 1

CLUSTAL X Multiple Sequence Alignment

KCNQ1 Numbering

hKCNQ1	MAAASSPPRA	E-----RKRW	GWGRLPGARR	GSAGLAKKCP	FSLELAEGG-	---P--AGGA	60
hKCNQ2	MVQKSR----	-----	NGGVYPGSPG	EKKLKVG---	-FVGLDPG--	-----APD	
hKCNQ3	MGLKARRAAG	AAGGGGDGGG	GGGGAANPAG	GDAAGDEE	RKVGLAPGDV	EQVTALGAG	
hKCNQ4	MAEAPPRR--	-----L	GLGPPPGDAP	RAELVALT--	-AVQSEQGE-	-----AGG	
hKCNQ5	MKDVES----	-----	GRGRVLLNSA	AARGDGLLLL	GTRAATLGG-	-----GGG	
	*		*		*		
hKCNQ1	LYAPIAPGAP	GPAPPASPAA	PAAPPVASDL	GPRPPVSLDP	RVSIYSTRRP	VLARTHVQGR	120
hKCNQ2	STRDGALLIA	G-----SEAP	KRGSILSKPR	AGGAGAGKPP	KRN-AFYRK-	-----LQNF	
hKCNQ3	ADKDGTLLE	GGG---RDEG	QRRTPQGIGL	LAKTPLSRPV	KRNNAKYRR-	-----IQTL	
hKCNQ4	GGSPRRLGLL	G-----SPLP	PGAPLPGPS	SGSACGQRS	SAAHKRYRR-	-----LQNW	
hKCNQ5	GLRESRRGKQ	G-----	ARMSLLGKPL	SYTS--SQSC	RRN-VKYRR-	-----VQNY	
		*			*	*	
hKCNQ1	VYNFLERPTG	WKCFVYHFAV	FLIVLVCLIF	SVLSTIEQYA	ALATGTLFWM	EIVLVVFFGT	180
hKCNQ2	LYNVLERPRG	W-AFIYHAYV	FLLVFSLVL	SVFSTIKEYE	KSSEGALYIL	EIVTIVVFGV	
hKCNQ3	IYDALERPRG	W-ALLYHALV	FLIVLGCLIL	AVLTTFKEYE	TVSGDWLLLL	ETFAIFIFGA	
hKCNQ4	VYNVLERPRG	W-AFVYHVFI	FLLVFSLVL	SVLSTIQEHQ	ELANECLLIL	EFVMIVVFGV	
hKCNQ5	LYNVLERPRG	W-AFIYHAFV	FLLVFGCLIL	SVFSTIPEHT	KLASSCLLIL	EFVMIVVFGV	
	*	**** *	**	** *	*	*	**

Site 1

Site 2

10

hKCNQ1 EYVRLWSAG CRSKYVGLWG RLRFAKRPIS IIDLIVVAS MVVLCVGSKG QVFATSAIRG 240
hKCNQ2 EYFVRIWAAG CCCRYRGWRG RLKFARKPFC VIDIMVLIA IAVLAAGSQG NVFATSALRS
hKCNQ3 EFALRIWAAG CCCRYKGRG RLKFARKPLC MLDIFVLIA VPVAVGNQG NVLATS-LRS
hKCNQ4 EYIVRVWSAG CCCRYRGWQG RFRFARKPFC VIDFIVFVAS VAVIAAGTQG NIFATSALRS
5 hKCNQ5 **EFIIRIWSAG CCCRYRGWQG RLRFAKRPFC VIDTIVLIA IAVVSAKTQG NIFATSALRS**
* * * * *

_____ Site 3 _____ Site _____

hKCNQ1 IRFLQILRML HVDRQGGTWR LLGSVVFHR QELITTLYIG FLGLIFSSYF VYLAEKDAVN 300
10 hKCNQ2 LRFLQILRMI RMDRRGGTWK LLGSVVYAHS KELVTAWYIG FLCLILASFL VYLAEK----
hKCNQ3 LRFLQILRML RMDRRGGTWK LLGSAICAHS KELITAWYIG FLTLILSSFL VYLVEKDVPE
hKCNQ4 MRFLQILRMV RMDRRGGTWK LLGSVVYAHS KELITAWYIG FLVLIFASFL VYLAEKD---
hKCNQ5 **LRFLQILRMV RMDRRGGTWK LLGSVVYAHS KELITAWYIG FLVLIFSSFL VYLVEKD---**
***** ** * * * * *

15 4 _____ Site 5 _____

hKCNQ1 -----ESGRV EFGSYADALW WGVVTVTIG YGDKVPQTWV GKTIASCFVS FAISFFALPA 360
hKCNQ2 -----GE--ND HFDTYADALW WGLITLTTIG YGDKYPQTWN GRLLAATFTL IGVSFFALPA
hKCNQ3 VDAQGEEMKE EFETYADALW WGLITLATIG YGDKTPKTWE GRLLAATFSL IGVSFFALPA
20 hKCNQ4 -----ANS DFSSYADSLW WGTITLTTIG YGDKTPHTWL GRVLAAGFAL LGISFFALPA
hKCNQ5 **-----ANK EFSTYADALW WGTITLTTIG YGDKTPLTWL GRLLSAGFAL LGISFFALPA**
* * * * *

_____ P-loop _____ Site 6 _____

25 hKCNQ1 GILGSGFALK VQKQKQKHF NRQIPAAASL IQTAWRCYAA E---NPDSST WKIYIRKAP- 420
hKCNQ2 GILGSGFALK VQEQHRQKHF EKRRNPAAGL IQSAWRFYAT NLSRTDLHST WQYYERTVT-
hKCNQ3 GILGSGFALK VQEQHRQKHF EKRRKPAEAL IQAAWRYAT NPNRIDLVAT WRFYESVVS-
hKCNQ4 GILGSGFALK VQEQHRQKHF EKRRMPAANL IQAAWRLYST DMSRAYLTAT WYYYDSILPS
hKCNQ5 **GILGSGFALK VQEQHRQKHF EKRRNPAANL IQCVWRSYAA D-EKSVSIAT WKPHLKALHT**
30 ***** ** * * * * *

hKCNQ1 -----RSH ¹²²TLLS----- PSPKPK----- -----KSVVV 480
hKCNQ2 -----VPM YRLIPP--LN QLELLRNLS KSGLAFRK-- -----DPP PEPSPSQKVS
35 hKCNQ3 -----FPF FRKE----- QLEAAS----- -----S--QKLG
hKCNQ4 FRELALLFEH VQRARNGGLR PLEVRRAPVP DGAPSRYPV ATCHRPGSTS FCPGESSRMG
hKCNQ5 **-----CSP TKKE----- QGEASS----- -----SQKLS**

- Alternatively Spliced -

40 hKCNQ1 KKKKFKLDKD NGVTPGEKML TVPH-ITCDP PEERRLDHFS VGDYDSSVRK SPTLLEVS-M 540
hKCNQ2 LKDRV-FSSP RGVAAGKGS PQAQTVRRSP SADQSLED-- ---SPSKVPK SWSFGDRSRA
hKCNQ3 LLDRVRLSNP RGSNTKGK-- -----LFTP LNVDIAEE-- ---SPSKEPK PVGLNNKERF
hKCNQ4 IKDRIRMGS QRRGTGSKQQ LAPPTMTSP SSEQVGEAT- ---SPTKVQK SWSFNDRTRF
hKCNQ5 **FKERVMA SP RGQSIKSRQA SVGD--RRSP STDITAEG-- ---SPTKVQK SWSFNDRTRF**

hKCNQ1 PHFMRTNS-- ----FAEDLD LEGETLLTPI TH-----ISQ LREHHRATIK VIRRMQYFVA 600
hKCNQ2 RQAFRIKGAA S-RQNSEEAS LPGEDIVDDK SCPCEVFTED LTPGLKVSIR AVCVMRFLVS
hKCNQ3 RTAFRMKAYA F-WQSSDAG T-GDPMAEDR GYGNDFFIED MIPTLKAAIR AVRILQFRLY
5 hKCNQ4 RASLRLKP-- --RTSAEDAP S--EEVAEEK SYQCELTVDV IMPAVKTVIR SIRILKFLVA
hKCNQ5 RPSLRLKSSQ PKPVIDADTA LGTDDVYDEK GCQCDVSVED LTPPLKTVIR AIRIMKFHVA

*

*

10 hKCNQ1 KKKFQQARKP YDVRDVIEQY SQGHLNLMVR IKELQRRLDQ SIGK-PSLFI SVS--EKS-- 660
hKCNQ2 KRKFKESELRP YDVM DVIEQY SAGHLDMLSR IKSLQSRVDQ IVGRGPAITD KDR--TKG--
hKCNQ3 KKKFKETLRP YDVKD VIEQY SAGHLDMLSR IKYLQTRIDM IFTPGPPSTP KHKKSQKGS
hKCNQ4 KRKFKESELRP YDVKD VIEQY SAGHLDMLSR IKSLQTRVDQ IVGRGPGDRK AREKGDG--
hKCNQ5 KRKFKESELRP YDVKD VIEQY SAGHLDMLSR IKSLQTRVDQ ILGKGQITSD KKSREKIT--

15

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A-domain

hKCNQ1 -----K DRG--SNTIG ARLNRVEDKV TQLDQRLALI TDMLHQLLSL 720
20 hKCNQ2 -----PAE AELPEDPSMM GRLGKVEKQV LSMEKKLDFL VNIYMQRMG
hKCNQ3 FTFPSQQSPR NEPYVARPST SEI-EDQSMM GKFKVVERQV QDMGKKLDFL VDMHMQHMER
hKCNQ4 -----PSD AEVVDEISMM GRVVKVEKQV QSIHKLDDL LGFYSRCLRS
hKCNQ5 -----AE HETTDLSML GRVVKVEKQV QSIESKLDCL LDIYQQVLRK

* * *

25

hKCNQ1 HGGSTPG--- SGGPPREGG-- -AHITQPCGS G--GSVDPEI FLPSNTLPTY EQLTVP-RRG 780
hKCNQ2 PPTETE---- AYFGAKEPEP APPYHSPEDS REHVDRHGC VKIVRSSST GQKNF----S
hKCNQ3 LQVQVT---- EYYPTKGTSS PAEAEKKEDN R-YSDLKTII CNYSETGPPE PPYSFH-QVT
30 hKCNQ4 GTSASLGA-- VQVPLFDPDI TSDYHSPVDH E-DISVSAQT LSISRVSSTN MD-----
hKCNQ5 GSASALALAS FQIPPFCEQ TSDYQSPVDS KDLGSAQNS GCLSRSTSAN ISRGLQFILT

hKCNQ1 PDEGS----- 840
35 hKCNQ2 APPAAPVQC PPSTSWQPQS HPRQGH---- ---GTSPVGD HGSLVRIPPP
hKCNQ3 IDKVSPYGFF AHDPVNLPRG GPSSGKV--- ---QATPPSS ATTYVERPTV
hKCNQ4 -----
hKCNQ5 PNEFSAQTFY ALSPTMHSQA TQVPISQSDG SAVAATNTIA NQINTAPKPA APTTLQIPPP

40

hKCNQ1 ----- 900
hKCNQ2 PAHERSL SAY GGGN-RASME FLRQEDTPGC R-PPEGLTRD SDTSISIPSV DHEELERSFS
hKCNQ3 LPILTL LLSR VSCH-SQADL QGPYS DRISP R-QRRSITRD SDTPLSLMSV NHEELERSPS
hKCNQ4 -----
45 **hKCNQ5 LPAIKHLPRP ETLHPNPAGL QESISDV TTC LVASKENVQV AQSNTLKDRS MRKSFD MGGE**

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hKCNQ1 ----- 960
hKCNQ2 GFSISQSKEN LDALNSCYAA VAPCAKVRPY IAEGESDTD- ----SDLCTP CGPPPRSATG
hKCNQ3 GFSISQDRDD YVFGPNGGSS WM---REKRY LAEGETDTD- ----TDPFTP SGSMPLSSTG
hKCNQ4 -----
5 hKCNQ5 TLLSVCPMVP KDLGKSLSVQ NLIRSTEELN IQLSGSESSG SRGSQDFYPK WRESKLFITD

hKCNQ1 ----- 976
hKCNQ2 EGPF GDVGWA GPRK--
hKCNQ3 DG-ISDSVWT PSNKPI
10 hKCNQ4 -----
hKCNQ5 EEVGPEETET DTFARI

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- hKCNQ1: Human KCNQ1 [*Wang, Q et al.*; Nature Genet. 1996 **12** 17-23]
- 15 hKCNQ2: Human KCNQ2 [*Biervert et al.*; Science 1998 **279** 403-406]
- hKCNQ3: Human KCNQ3 [*Schroeder et al.*; Nature 1998 **396** 687-690]
- hKCNQ4: Human KCNQ4 [*Kubisch et al.*; Cell 1999 **96** (3) 437-46]
- hKCNQ5: Human KCNQ5; A protein of the invention
- No amino acid in this position.
- 20 * Indicates positions which holds a single, fully conserved residue (Conserved regions).

Preferred variants are the splice variants at positions 432-476 (KCNQ1 Numbering) holding the following amino acid residues:

- 25 1) KKE----- QGEASS----- ----NKFC SNKQKLFRMY TSRKQS;
 2) KKE----- QGEASS----- ----
 3) -----
 4) ----- ----NKFC SNKQKLFRMY TSRKQS.

Another preferred variants is G329S (KCNQ1 numbering), or
 30 KCNQ5/G278S ("KCNQ5 numbering").

Biological Activity

Ion channels are excellent targets for drugs. The polynucleotide of the invention encodes a potassium channel, which has been termed KCNQ5.

- 35 KCNQ5, or heteromeric channels containing the KCNQ5 subunit, may be a particularly interesting target for the treatment of diseases or adverse conditions of the CNS, including affective disorders, Alzheimer's disease, anxiety, ataxia, CNS damage caused by trauma, stroke or neurodegenerative illness, cognitive deficits, compulsive behaviour, dementia, depression, Huntington's disease, learning deficiencies, mania,
 40 memory impairment, memory disorders, memory dysfunction, motion disorders, motor

disorders, motor neuron diseases, myokymia, neurodegenerative diseases, Parkinson's disease and Parkinson-like motor disorders, phobias, Pick's disease, psychosis, schizophrenia, seizures, incl. epileptic seizures, spinal cord damage, stroke, tremor, seizures, convulsions and epilepsy.

5 The novel polynucleotides of the invention may in itself be used as a therapeutic or diagnostic agent. For gene therapy, the person skilled in the art may use sense or antisense nucleic acid molecules as therapeutic agents for KCNQ-related indications.

10 Heteromers Formed by KCNQ Subunits

 The KCNQ channels described so far function physiologically as heteromers. KCNQ1 associates with KCNE1 (also known as minK or Isk); KCNQ2 and KCNQ3 form heteromeric channels that underlie the M-current, an important determinant of neuronal excitability that is regulated by several neurotransmitters, and
15 KCNQ4 is supposed to combine with KCNQ3 to mediate the I_M -like current in the outer hair cells.

 Like other KCNQ channel subunits, KCNQ5 may interact with other subunits, e.g. KCNE1 or other KCNQ channel subunits, and in particular with KCNQ3, and with KCNQ4. Currents from homomeric KCNQ3 are very small and often cannot
20 be distinguished from *Xenopus* oocyte background currents. Co-expression of KCNQ3 with KCNQ5 markedly increased current amplitudes. Co-expression of KCNQ4 with KCNQ5 markedly decreased current amplitudes.

Antibodies

25 The polypeptides of the invention can be used to produce antibodies which are immunoreactive or bind to epitopes of these polypeptides. Polyclonal antibodies which consist essentially of pooled monoclonal antibodies with different specificities, as well as distinct monoclonal antibody preparations may be provided. Polyclonal antibodies which are made up of pooled monoclonal antibodies with different
30 specificities, as well as distinct monoclonal antibody preparations may be provided.

 The preparation of polyclonal and monoclonal antibodies is well known in the art. Polyclonal antibodies may in particular be obtained as described by e.g. *Green et al.*: "Production of Polyclonal Antisera" in Immunochemical Protocols (Manson, Ed.); Humana Press, 1992, Pages 1-5; *Coligan et al.*: "Production of
35 Polyclonal Antisera in rabbits, rats, Mice and Hamsters" in Current Protocols in Immunology, 1992, Section 2.4.1; and *Ed Harlow and David Lane* (Eds.) in "Antibodies; A laboratory manual", Cold Spring Harbor Lab. Press 1988; which protocols are hereby incorporated by reference.

Monoclonal antibodies may in particular be obtained as described by e.g. *Kohler & Milstein*, Nature 1975 **256** 495; Coligan et al. in Current Protocols in Immunology, 1992, Sections 2.5.1 - 2.6.7; *Harlow et al.* in Antibodies: A Laboratory Manual; Cold Spring Harbor Pub., 1988, Page 726; which protocols are hereby
5 incorporated by reference.

Briefly, monoclonal antibodies may be obtained by injecting e.g. mice with a composition comprising an antigen, verifying the presence of antibody production by removing a serum sample, removing the spleen to obtain B lymphocytes, fusing the B lymphocytes with myeloma cells to produce hybridomas, cloning the hybridomas,
10 selecting positive clones that produce the antibodies to the antigen, and isolating the antibodies from the hybridoma cultures.

Monoclonal antibodies can be isolated and purified from hybridoma cultures by a variety of well-established techniques, including affinity chromatography with protein A Sepharose, size-exclusion chromatography, and ion-exchange
15 chromatography, see. e.g. *Coligan et al.* in Current Protocols in Immunology, 1992, Sections 2.7.1 - 2.7.12, and Sections 2.9.1 - 2.9.3; and *Barnes et al.*: "Purification of Immunoglobulin G (IgG)" in Methods in Molecular Biology; Humana Press, 1992, Vol. 10, Pages 79-104.

The polyclonal or monoclonal antibodies may optionally be further purified,
20 e.g. by binding to and elution from a matrix to which the polypeptide, to which the antibodies were raised, is bound.

Antibodies which bind to the polypeptide of the invention can be prepared using an intact polypeptide or fragments containing small peptides of interest as the immunising antigen. The polypeptide used to immunise an animal may be obtained by
25 recombinant DNA techniques or by chemical synthesis, and may optionally be conjugated to a carrier protein. Commonly used carrier proteins which are chemically coupled to the peptide include keyhole limpet hemocyanin (KLH), thyroglobulin, bovine serum albumin (BSA), and tetanus toxoid. The coupled peptide may then be used to immunise the animal, which may in particular be a mouse, a rat, a hamster or
30 a rabbit.

Genetically Manipulated Cells

In a third aspect the invention provides a cell genetically manipulated by the incorporation of the heterologous polynucleotide of the invention. The cell of the
35 invention may in particular be genetically manipulated to transiently or stably express, over-express or co-express a KCNQ5 channel subunit as defined above. Methods of transient and stable transfer are known in the art.

The polynucleotide of the invention may be inserted into an expression vector, e.g. a plasmid, virus or other expression vehicle, and operatively linked to

expression control sequences by ligation in a way that expression of the coding sequence is achieved under conditions compatible with the expression control sequences. Suitable expression control sequences include promoters, enhancers, transcription terminators, start codons, splicing signals for introns, and stop codons, all maintained in the correct reading frame of the polynucleotide of the invention so as to permit proper translation of mRNA. Expression control sequences may also include additional components such as leader sequences and fusion partner sequences.

The promoter may in particular be a constitutive or an inducible promoter. When cloning in bacterial systems, inducible promoters such as pL of bacteriophage γ , plac, ptrp, ptac (ptrp-lac hybrid promoter), may be used. When cloning in mammalian systems, promoters derived from the genome of mammalian cells, e.g. the TK promoter or the metallothionein promoter, or from mammalian viruses, e.g. the retrovirus long terminal repeat, the adenovirus late promoter or the vaccinia virus 7.5K promoter, may be used. Promoters obtained by recombinant DNA or synthetic techniques may also be used to provide for transcription of the polynucleotide of the invention.

Suitable expression vectors typically comprise an origin of expression, a promoter as well as specific genes which allow for phenotypic selection of the transformed cells, and include vectors like the T7-based expression vector for expression in bacteria [*Rosenberg et al*; Gene 1987 **56** 125], the pMSXND expression vector for expression in mammalian cells [*Lee and Nathans*, J. Biol. Chem. 1988 **263** 3521], baculovirus derived vectors for expression in insect cells, and the oocyte expression vector PTLN [*Lorenz C, Pusch M & Jentsch T J*: Heteromultimeric CLC chloride channels with novel properties; Proc. Natl. Acad. Sci. USA 1996 **93** 13362-13366].

In a preferred embodiment, the cell of the invention is an eukaryotic cell, in particular a mammalian cell, an oocyte, or a yeast cell. In a more preferred embodiment, the cell of the invention is a human embryonic kidney (HEK) cell, a HEK 293 cell, a BHK21 cell, a Chinese hamster ovary (CHO) cell, a *Xenopus laevis* oocyte (XLO) cell, a COS cell, or any other cell line able to express KCNQ potassium channels.

When the cell of the invention is an eukaryotic cell, incorporation of the heterologous polynucleotide of the invention may be in particular be carried out by infection (employing a virus vector), by transfection (employing a plasmid vector), or by calcium phosphate precipitation, microinjection, electroporation, lipofection, or other physical-chemical methods known in the art.

In a further preferred embodiment, the cell of the invention is genetically manipulated to co-express KCNQ5 and KCNQ1 channel subunits; KCNQ5 and KCNQ2 channel subunits; KCNQ5 and KCNQ3 channel subunits; KCNQ5 and

KCNQ4 channel subunits; KCNQ5 and KCNQ1 and KCNQ2 channel subunits; KCNQ5 and KCNQ1 and KCNQ3 channel subunits; KCNQ5 and KCNQ2 and KCNQ3 channel subunits; KCNQ5 and KCNQ1 and KCNQ4 channel subunits; KCNQ5 and KCNQ2 and KCNQ4 channel subunits; KCNQ5 and KCNQ3 and KCNQ4 channel subunits; KCNQ5 and KCNQ1 and KCNQ2 and KCNQ3 channel subunits; KCNQ5 and KCNQ1 and KCNQ2 and KCNQ4 channel subunits; KCNQ5 and KCNQ1 and KCNQ3 and KCNQ4 channel subunits, or KCNQ5 and KCNQ2 and KCNQ3 and KCNQ4 channel subunits.

In another preferred embodiment, membrane preparations are provided. The membrane preparations of the invention may typically be used for screening purposes, and may be obtained by standard techniques.

In a preferred embodiment, frozen intact cells of the invention are homogenised while in cold water suspension and a membrane pellet is collected after centrifugation. The pellet may then be washed in cold water and dialysed to remove endogenous ligands that could compete for binding in the assays. The dialysed membranes may be used as such, or after storage in lyophilised form.

KCNQ5 Active Chemical Compounds

In another aspect the invention relates to chemical compounds capable of binding to, and showing activity at potassium channels containing one or more KCNQ5 subunits. In the context of this invention such compounds are termed KCNQ5 active compounds.

The KCNQ5 active compounds of the invention have therapeutic potential, and may be used for the manufacture of pharmaceutical compositions.

The KCNQ5 active compounds of the invention may in particular be used in diagnosis, treatment, prevention or alleviation of diseases related to diseases or adverse conditions of the CNS, including affective disorders, Alzheimer's disease, anxiety, ataxia, CNS damage caused by trauma, stroke or neurodegenerative illness, cognitive deficits, compulsive behaviour, dementia, depression, Huntington's disease, mania, memory impairment, memory disorders, memory dysfunction, motion disorders, motor disorders, neurodegenerative diseases, Parkinson's disease and Parkinson-like motor disorders, phobias, Pick's disease, psychosis, schizophrenia, spinal cord damage, stroke, tremor, seizures, convulsions and epilepsy.

Currently two compounds have been identified. As a preferred embodiment the invention therefore provides 1,3-dihydro-1-phenyl-3,3-bis-(4-pyridylmethyl)-2H-indol-2-one (Linopirdine) and 10,10-bis-(4-pyridinyl-methyl)-9-(10H)-anthracenone (XE991) for use in the manufacture of a pharmaceutical composition for the diagnosis, treatment, prevention or alleviation of the above diseases.

Screening of Drugs

In a further aspect the invention provides methods for screening for KCNQ5 active compounds, i.e. chemical compounds capable of binding to, and showing activity at potassium channels containing one or more KCNQ5 subunits. The activity determined may be inhibitory activity, stimulating activity, or other modulatory activity. In particular the KCNQ5 active compound may induce a second messenger response, which cause a change of the molecular characteristics of the cell, e.g. the ion flux, enzyme activation, changes in the level of intracellular Ca^{2+} or H^+ , changes cyclic nucleotides such as cAMP, cADP, cGMP, and cGDP, etc.

Therefore, in another aspect, the invention provides a method for identifying functional ligands for a human potassium channel, comprising a KCNQ5 subunit, which method comprises transfecting cells with one or more polypeptides of the invention, encoding a KCNQ5 channel subunit, and detecting the effect on the signal transduction pathway caused in these cells by binding of the ligands to the receptor by a reporter system.

Such chemical compounds can be identified by one of, or both methods described below.

Binding Studies

Binding studies are usually carried out by subjecting the target to binding with a labelled, selective agonist (binding agent), to form a labelled complex, followed by determination of the degree of displacement caused by the test compound upon addition to the complex.

In a specific aspect the invention provides a method of screening a chemical compound for capability of binding to a potassium channel comprising at least one KCNQ5 channel subunit, which method comprises the steps of (i) subjecting a KCNQ5 channel subunit containing cell to the action of a KCNQ5 binding agent to form a complex with the KCNQ5 channel subunit containing cell; (ii) subjecting the complex of step (i) to the action of the chemical compound to be tested; and (iii) detecting the displacement of the KCNQ5 binding agent from the complex with the KCNQ5 channel subunit containing cell.

The KCNQ5 channel subunit containing cell preferably is a cell of the invention as described above.

The KCNQ5 binding agent preferably is a radioactively labelled 1,3-dihydro-1-phenyl-3,3-bis-(4-pyridylmethyl)-2H-indol-2-one (Linopirdine); or 10,10-bis-(4-pyridinyl-methyl)-9-(10H)-anthracenone (XE991).

In a even more preferred embodiment, the binding agent is labelled with ^3H , and the displacement of the KCNQ5 binding agent from the complex with the

KCNQ5 channel subunit containing cell is detected by measuring the amount of radioactivity by conventional liquid scintillation counting.

Activity Studies

5 The KCNQ5 channel agonists may affect the potassium channel in various ways. The agonist may in particular show inhibitory activity, stimulating activity, or other modulatory activity.

 In a specific aspect the invention provides a method for determining the activity at potassium channels containing one or more KCNQ5 subunits. According to
10 this method a KCNQ5 channel subunit containing cell is subjected to the action of the chemical compound to be tested, and the activity is detected by way of monitoring the membrane potential, the current, the potassium flux, or the secondary calcium influx of the KCNQ5 channel subunit containing cell, preferably a genetically manipulated as described above.

15 The membrane potential and the current may be monitored by electrophysiologic methods, including patch clamp techniques, such as current clamp technology and two-electrode voltage clamp technology, or by spectroscopic methods, such as fluorescence methods.

 In a preferred embodiment, monitoring of the membrane potential of the
20 KCNQ5 channel subunit containing cell is performed by patch clamp techniques.

 In another preferred embodiment, monitoring of the membrane potential of the KCNQ5 channel subunit containing cell is performed by spectroscopic methods, e.g. using fluorescence methods. In a more specific embodiment, the KCNQ5 channel subunit containing cell is mixed with a membrane potential indicating agent, that allow
25 for a determination of changes in the membrane potential of the cell, caused by the addition of the test compound. The membrane potential indicating agent may in particular be a fluorescent indicator, preferably DIBAC₄(3), DiOC₅(3), and DiOC₂(3).

 In yet a preferred embodiment, monitoring of the membrane potential of the KCNQ5 channel subunit containing cell is performed by spectroscopic methods, e.g.
30 using a FLIPR assay (Fluorescence Image Plate Reader; available from Molecular Devices).

Screening of Genetic Material

 In a further aspect the invention relates to the use of a polynucleotide
35 sequence of the invention for the screening of genetic materials. By this method, individuals bearing a gene identical or homologous to a polynucleotide of the invention may be identified.

 In the screening method of the invention, a polynucleotide of the invention, or any fragment or sub-sequence hereof, is employed. For the identification of

individuals bearing mutated genes preferably the mutated forms of the polynucleotide represented by SEQ ID NO: 1 are employed.

In the screening method of the invention only short sequences needs to be employed depending on the actual method used. For SSCA, several hundreds of
5 base pairs may be needed, for oligonucleotide or PCR hybridisation only of from about 10 to about 50 basepairs may be needed.

The screening may be accomplished by conventional methods, including hybridisation, SSCA analysis, and microarray technology (DNA chip technology). The hybridisation protocol described above represents a suitable protocol for use in a
10 screening method of the invention.

Transgenic Animals

Transgenic animal models provide the means, *in vivo*, to screen for therapeutic compounds. Since KCNQ5 is expressed also in brain, they may be helpful
15 in screening for drugs effective in CNS disorders, e.g. epilepsy.

By transgene is meant any piece of polynucleotide which is inserted by artifice into a cell, and thus becomes part of the genome of the organism that develops from that cell. Such a transgene may include a gene which is partly or entirely heterologous (i.e. foreign) to the transgenic organism, or it may represent a
20 gene homologous to an endogenous gene of the organism.

By a transgenic animal is meant any organism holding a cell which includes a polynucleotide sequence which is inserted into that cell by artifice, and which cell becomes part of the transgenic organism which develops from that cell. Such a transgene may be partly or entirely heterologous to the transgenic animal. Although
25 transgenic mice represent a preferred embodiment of the invention, other transgenic mammals including, but not limited to transgenic rodents (e.g. hamsters, guinea pigs, rabbits and rats), and transgenic pigs, cattle, sheep and goats may be created by standard techniques and are included in the invention.

Preferably, the transgene is inserted by artifice into the nuclear genome.
30

Knock-out and Knock-in Animals

The transgenic knock-out animal models may be developed by homologous recombination of embryonic stem cells with constructs containing genomic sequence from the *KCNQ5* gene, that lead to a loss of function of the gene
35 after insertion into the endogenous gene.

By knock-out mutation is meant an alteration in the polynucleotide sequence that reduces the biological activity of the polypeptide normally encoded therefrom. In order to create a true knock-out model, the biological activity of the expressed polypeptide should be reduced by at least 80% relative to the un-mutated

gene. The mutation may in particular be a substitution, an insertion, a deletion, a frameshift mutation, or a mis-sense mutation. Preferably the mutation is a substitution, an insertion or a deletion.

To further assess the role of KCNQ5 at an organism level, the generation of an animal, preferably a mouse, lacking the intact *KCNQ5* gene, or bearing a mutated *KCNQ5* gene, is desired.

A replacement-type targeting vector, which may be used to create a knock-out model, may be constructed using an isogenic genomic clone, e.g. from a mouse strain such as 129/Sv (Stratagene Inc., La Jolla, CA). The targeting vector may be introduced into a suitably-derived line of embryonic stem (ES) cells by electroporation to generate ES cell lines that carry a profoundly truncated form of the *KCNQ5* gene. The targeted cell lines may then be injected into a mouse blastula stage embryo to generate chimeric founder mice. Heterozygous offspring may be interbred to homozygosity.

Animal models for over-expression may be generated by integrating one or more polynucleotide sequence of the invention into the genome according to standard techniques.

The procedures disclosed herein involving the molecular manipulation of nucleic acids are known to those skilled in the art, and are described by e.g. *Fredrick MA et al.* [*Fredrick MA et al.: Short Protocols in Molecular Biology*; John Wiley and Sons, 1995] and *Sambrook et al.* [*Sambrook et al.: Molecular Cloning: A Laboratory Manual*; 2. Ed., Cold Spring Harbor Lab.; Cold Spring Harbor, NY 1989], and in *Alexandra LJ (Ed.): Gene Targeting: A practical approach*; Oxford University Press (Oxford, New York, Tokyo), 1993.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is further illustrated by reference to the accompanying drawing, in which:

Fig. 1 shows the electrophysiological properties of KCNQ5 currents [$I/\mu A$ vs. time/seconds]. Two-electrode voltage-clamp current traces from a *Xenopus* oocyte injected with KCNQ5 cRNA. Starting from a holding potential of -80 mV, cells were clamped for 2 seconds to voltages between -80 and +40 mV, in +10 mV steps, followed by a constant test pulse to -30 mV; and

Fig. 2 shows the electrophysiological properties of currents arising from the co-expression of KCNQ5 with KCNQ3 [$I/\mu A$ vs. time/seconds]. Starting from a holding potential of -80 mV cells were clamped for 2 seconds to voltages between -80 and +40 mV, in +10 mV steps, followed by a constant test pulse to -30 mV; and

Fig. 3 shows the electrophysiological properties of currents arising from the co-expression of KCNQ5 with KCNQ4 (2B) [I/μA vs. time/seconds]. Starting from a holding potential of -80 mV cells were clamped for 2 seconds to voltages between -80 and +40 mV, in +10 mV steps, followed by a constant test pulse to -30 mV;

5 Figs. 4A-G show the electrophysiological properties of KCNQ5. Both the splice variant I (found in brain) and splice variant III (found in muscle) were expressed in *Xenopus* oocytes and examined by two-electrode voltage clamping. Both variants activate slowly upon depolarisation, but form I (4A) initially activates slower than the muscle form III (4B). Starting from a holding potential of -80 mV, the voltage was
10 stepped for 0.8 seconds to values between -100 and +40 mV in steps of 10 mV, followed by a voltage step to -30 mV (see inset, panel A). Channel activation by depolarization was fitted (for 2 sec. steps) by a sum of three exponential functions. For a step to +20 mV, the rate constants were $\tau_1 = 37.2 \pm 2.2$ ms, $\tau_2 = 246 \pm 17$ ms, and $\tau_3 = 1112 \pm 91$ ms for splice variant I, while these constants were $\tau_1 = 24.5 \pm 0.8$
15 ms, $\tau_2 = 163 \pm 6$ ms, and $\tau_3 = 1690 \pm 46$ ms (\pm SEM, n=16). This difference in kinetics also results in different curves when a typical M-current protocol is used (4C, variant I; 4D, variant III). Variant I induces currents that kinetically resemble M-currents. In this protocol, the membrane voltage is clamped for 1 second to voltages between -30 and -90 mV in steps of -10 mV, from a holding potential of -30 mV. This
20 was followed by a step to -30 mV (panel C, inset). (4E, 4F), apparent open probabilities of variants I (4E) and variant III (4F) as a function of voltage obtained from tail current analysis as described in Methods. Mean values obtained from 12 oocytes are shown. Fitting a Boltzmann equation yielded $V_{1/2} = -46 \pm 1$ mV and an apparent gating charge of $z = 2.8 \pm 0.1$ for isoform I, and $V_{1/2} = -48 \pm 1$ mV and an
25 apparent gating charge of $z = 2.5 \pm 0.1$ for isoform III. For this fit, values at potentials more positive than +10 mV were excluded, as these are probably affected by a second (inactivation) gating process which leads to a decrease of apparent p_{open} at more positive potentials. (4G), ion selectivity of KCNQ5 currents (variant I). Extracellular sodium was replaced by equimolar amounts of potassium. The reversal
30 potential is shown as a function of the potassium concentration. This yielded a slope of 51 mV/decade potassium concentration, indicating a highly selective potassium channel. Data are from 10 oocytes from 2 different batches;

Figs. 5A-C show the pharmacology of KCNQ5 and KCNQ3/5 heteromers. (5A) Inhibition of KCNQ5 homomers by extracellular linopirdine (*down triangles*),
35 XE991 (*up triangles*) and TEA (*squares*). IC₅₀ values of 51 ± 5 μM, 65 ± 4 μM and 71 ± 17 mM, respectively, were obtained from the plotted fit curves. (5B) Niflumic acid alters the voltage dependence of the apparent p_{open} . In the presence of 500 μM niflumic acid (*open circles*), the voltage dependence is shifted about 20 mV towards negative potentials. (5C) TEA sensitivity is altered in KCNQ3/5 heteromers.

Coexpression of KCNQ5 and KCNQ3 (1:1) (*diamonds*) increased the IC_{50} value to ~ 200 mM, coexpression with the KCNQ3 (T323Y) mutant (*circles*) decreased the IC_{50} to ~ 30 mM. Data points in panels A and C are the means \pm SEM of 4 to 12 individual measurements. p_{open} was determined as in Fig. 3;

5 Fig. 6 shows the inhibition of KCNQ5 currents by stimulating M1 receptors which were co-expressed in *Xenopus* oocytes:

(6A) currents before stimulating the M1 receptor;

(6B) current observed 3 minutes after applying 10 μ M muscarine. The pulse protocol is shown in the inset of panel b. No effect of 10 μ M muscarine or
10 oxotremorine methiodide was found in oocytes injected with KCNQ5 alone; and

Figs. 7A-C show the interactions between KCNQ2 and KCNQ5 (7A, 7B) and KCNQ3 and KCNQ5 (7C):

(7A) currents at the end of a two second pulse to 0 mV from a holding potential of -80 mV of oocytes injected with different combinations of KCNQ cRNAs
15 (always 10 ng total amount of RNA). The current amplitude elicited by co-injecting KCNQ2 and KCNQ5 could be explained by a linear superposition of currents. Co-injection of KCNQ5 with the dominant negative mutant KCNQ2(G279S) or of KCNQ2 with the equivalent mutant KCNQ5(G278S) lead to a roughly 50% reduction in current amplitude, which is consistent with a lack of interaction since only 50% of WT cRNA
20 was injected;

(7B) normalized current traces of experiments used for panel (A). Currents elicited by the depolarizing pulse to 0 mV are shown. KCNQ2 (labeled Q2) activates faster than KCNQ5 (Q5), and the co-expression of both yielded currents that may be explained by a linear superposition. Co-injecting KCNQ2 with the dominant negative
25 (and otherwise non-functional) mutant KCNQ5(G278S) yielded currents that were kinetically similar to KCNQ2, and currents from a KCNQ5/KCNQ2(G279S) co-injection resembled KCNQ5 currents;

(7C), interactions between KCNQ3 and KCNQ5 measured as in panel (a). KCNQ3 yields only very small currents in *Xenopus* oocytes. Currents were enlarged
30 when KCNQ5 was co-expressed with small amounts of KCNQ3, and reduced when co-expressed with larger amounts. The dominant negative mutant KCNQ3(G318S) decreased currents significantly below 50% of WT KCNQ5 currents that would be expected from the injected 50% of WT KCNQ5 cRNA in this experiment.

35

EXAMPLES

The invention is further illustrated with reference to the following examples which are not intended to be in any way limiting to the scope of the invention as claimed.

Example 1

Cloning and Characterisation of KCNQ5 cDNA

Using a near full-length KCNQ3 potassium channel cDNA as a probe, a human thalamus cDNA λ GT11 phage library (Clontech, #HL5009b) was screened, and a partial cDNA clone encoding a protein fragment homologous to KCNQ potassium channels was isolated. It was distinct from the known members KCNQ1 (KvLQT1), KCNQ2, KCNQ3 and KCNQ4. We named the novel gene *KCNQ5*. Overlapping cDNA's containing the entire open reading frame were obtained by re-screening the cDNA library and by extending the 5' end in RACE (rapid amplification of cDNA ends) experiments using a Marathon kit (Clontech) with human brain cDNA. A complete cDNA was assembled and cloned into the oocyte expression vector PTLN [Lorenz C, Pusch M & Jentsch T J: Heteromultimeric CLC chloride channels with novel properties; Proc. Natl. Acad. Sci. USA 1996 **93** 13362-13366].

The cDNA encodes a polypeptide of 897 amino acids with a predicted mass of 99 kDa (SEQ ID NO: 2). Its overall amino-acid identity to KCNQ1, KCNQ2, KCNQ3 and KCNQ4 is 43%, 58%, 54%, and 61% respectively. Together with these proteins, it forms a distinct branch of the superfamily of voltage-gated potassium channels. As a typical member of this gene family, KCNQ5 has 6 predicted transmembrane domains and a P-loop between transmembrane domains S5 and S6. In potassium channels, which are tetramers of identical or homologous subunits, four of these highly conserved P-loops combine to form the ion-selective pore. As other KCNQ channels, KCNQ5 has a long predicted cytoplasmic carboxy terminus that accounts for about half of the protein. A conserved region present in the carboxy termini of KCNQ1, -2, -3 and -4 is also present in KCNQ5.

The sequence of KCNQ5 predicts several potential sites for phosphorylation by protein kinase C and one for protein kinase A. In contrast to KCNQ1 and KCNQ2, however, it lacks an amino terminal consensus site for cAMP-dependent phosphorylation.

A human multiple tissue Northern blot (Clontech, #7760-1) was probed with a cDNA fragment of KCNQ5. The fragment was labelled with ^{32}P using the Rediprime labelling kit (Amersham). Hybridisation was performed in ExpressHyb solution according to the instructions of the manufacturer (Clontech). The filter was then exposed to Kodak BioMax film for 4 days.

Northern analysis of *KCNQ5* expression in human tissues revealed a band of ≈ 9 kb in brain.

Example 2**Functional expression of KCNQ5 potassium channel subunits**

KCNQ5 was expressed in *Xenopus* oocytes and its activity was investigated by two-electrode voltage clamping.

After linearization of the *KCNQ5*-containing pTLN vector with HpaI, capped cRNA was transcribed *in vitro* using the mMessage mMachine cRNA synthesis kit (Ambion). Usually 5 – 15 ng of cRNA were injected into *Xenopus* oocytes previously isolated by manual defolliculation and short collagenase treatment. In co-expression experiments cRNAs were injected at a 1:1 ratio. Oocytes were kept at 17°C in modified Barth's solution (90 mM NaCl, 1 mM KCl, 0.41 mM CaCl₂, 0.33 mM Ca(NO₃)₂, 0.82 mM MgSO₄, 10 mM HEPES, 100 U penicillin–100 µg streptomycin/ml, pH 7.6).

Standard two-electrode voltage-clamp measurements were performed at room temperature 2–4 days after injection using a Turbotec 05 amplifier (npi instruments, Tamm, Germany) and pClamp 5.5 software (Axon Instruments). Currents were usually recorded in ND98 solution (see Table 2). Linopirdine (RBI, Natick, MA) was prepared as a 100 mM stock solution in DMSO and added to a final concentration of 200 µM to ND98.

Table 2**Solution contents (Concentrations in mM)**

ND98	ND 100	KD100	Rb100	Cs100
98 NaCl 2 KCl 0.2 CaCl ₂ 2.8 MgCl ₂	100 NaCl 0.2 CaCl ₂ 2.8 MgCl ₂	100 KCl 0.2 CaCl ₂ 2.8 MgCl ₂	100 RbCl 0.2 CaCl ₂ 2.8 MgCl ₂	100 CsCl 0.2 CaCl ₂ 2.8 MgCl ₂
5 mM HEPES, pH 7.4				

To determine the voltage dependence of apparent open probability, oocytes were clamped for 2 seconds to values between -80 mV to +40 mV, in 10 mV steps, followed by a constant -30 mV test pulse. Tail currents extrapolated to t=0 were obtained from a mono-exponential fit, normalised to the value at 0 mV and used for the analysis of apparent p_{open} . Data analysis used PClamp6 and Microcal Origin 5.0.

Similar to KCNQ1, KCNQ2, KCNQ3, and KCNQ4 also KCNQ5 yielded currents that activated upon depolarisation (Fig. 1). Compared to KCNQ1, KCNQ2

and KCNQ2/3 channels, however, current activation was slower and occurred with a time constant in the order of 600 ms at +20mV (KCNQ2/KCNQ3 channels have a corresponding time constant of ≈ 300 ms). Deactivation of currents at physiological resting potentials (≈ -30 mV) was considerably faster (Fig. 1). Similar to KCNQ2, macroscopic currents often showed some inward rectification at positive potentials. KCNQ5 currents were inhibited by more than 80% by 5 mM Ba⁺⁺.

KCNQ1 assembles with minK (also known as KCNE1 or Isk) to form channels that yield larger currents and activate much slower. We therefore tested by co-expression whether minK affects KCNQ5 as well. At concentrations (1ng minK cRNA per oocyte) leading to drastic changes in KCNQ1 currents in parallel experiments, there was just a slight change in KCNQ5 currents.

Different KCNQ subunits can form heteromeric channels. Co-expression of KCNQ2 with KCNQ3, but not with KCNQ1, gave currents that were about tenfold larger than those from homomeric channels. Since also KCNQ2, KCNQ3 and KCNQ4 are expressed in the brain, we investigated whether these proteins interact functionally. Oocytes co-injected (at the same total cRNA concentration) with KCNQ2 and KCNQ5 cRNAs yielded currents that seemed not different from a linear superposition of currents from the respective homomeric channels.

By contrast, co-expression of KCNQ3 with KCNQ5 yielded currents that were significantly larger than could be explained by a superposition of currents from the respective homomeric channels (Figs. 2A). Further, co-expression of KCNQ5 and KCNQ4 decreased currents when compared to homomeric channels (Fig. 2B).

Linopirdine, a potent and rather specific inhibitor for M-currents, nearly completely inhibits KCNQ2/KCNQ3 channels at a concentration of 200 μ M.

This concentration of Linopirdine inhibited KCNQ5 by about 80%.